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A VHF INTRUDER DETECTION SYSTEM: TESTS ON A C-5A AIRCRAFT

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report describes tests of a portable VHF Intrusion Detection System that were carried out in conjunction with a C-5A aircraft. The system consisted of a leaky coaxial cable surrounding the aircraft that acted as a distributed antenna, monopole antennas located within the cable perimeter that received the radiated signal, and electronic signal processing equipment. The tests demonstrated the feasibility of using this system to: (1) protect the C-5A aircraft in the up position as well as in the download position, and (2) protect any large aircraft.		

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20. (Cont)

Data is given on system response for various positions of the receiving antennas. By proper placement of two receiving antennas there was complete azimuthal coverage.

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Preface

The authors wish to thank all the members of the 436th SP Squadron at Dover AFB, Delaware who contributed their help.

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A VHF Intruder Detection System: Tests on a C-5A Aircraft

1. INTRODUCTION

One of the objectives, stated in two EDS documents,^{1,2} was to develop a mobile intruder detection system for isolated high value resources. The need for such a system exists because present systems, despite varying degrees of effectiveness, suffer from a variety of severe deficiencies. Among these are a high false alarm rate under certain environmental conditions, critical set-up procedures, and difficulty in controlling the extent and uniformity of the zone of protection. Therefore a new class of radio frequency intruder detection sensors^{3,4,5} operating in the VHF range, has been developed to eliminate the shortcomings of present systems. This report is the fourth, and final, of the inhouse series, dealing with these new sensors.

The first report³ presented several basic intrusion detection techniques and gave experimental results using these schemes to protect a trailer. From that data, as explained in the second report⁴ a prototype VHF intrusion detection system was designed, built, and tested on isolated and clustered vehicles. The third report⁵ contained the experimental data of field tests conducted with a B-52 aircraft as the resource. This fourth report gives the experimental results using a C-5A aircraft as the resource to be protected. In addition to the inhouse work, Northeastern

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(Because of the large number of references cited above, they will not be listed here. See Reference Page 35, for References 1 through 5.)

University (under contract to this laboratory) in parallel work, has developed a prototype portable field system. Inhouse efforts emphasized investigation of the basic electromagnetic principles underlying the operation of the detection system and the application of these findings to protecting specific resources. The North-eastern University efforts concentrated on developing and fabricating the electronic circuitry of the system into a compact lightweight package. Their results have been published in a separate report.⁶

2. GENERAL DESCRIPTION OF EXPERIMENT

The Individual Resource Protection System (IRPS) consists of a leaky coaxial cable that encircles the protected resource(s), a monopole antenna(s) placed within the perimeter formed by the cable, and electronic signal processing circuits (see Figure 1).

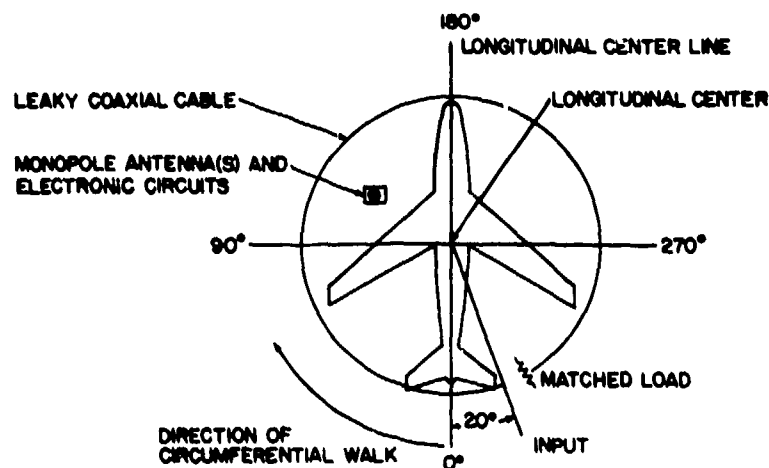


Figure 1. Schematic of Test Layout

When an intruder nears or crosses the leaky coaxial cable, the received signal is modified, producing a change in the quiescent level of the detected signal. This change, processed by appropriate electronic circuitry, then activates the alarm

6. Rochefort, J. S., Sukys, R., and Poirier, N. C. (1978) An Area Intrusion Detection and Alarm System RADC-TR-78-258.

circuit. A simplified block diagram of the system circuit is shown in Figure 2. The low-pass AGC filter sets the gain of the receiver and the level of the transmitted signal to values appropriate for existing conditions. Its frequency response allows only long-time-constant changes, such as might be produced by environmental drifts, to change signal amplitude levels. The bandpass filter passes only those changes in the detected signal that correspond to human frame motion. Because the threshold detector requires a minimum signal to be activated, it discriminates against nuisance alarms caused by small animals. The system also includes self-test circuits.

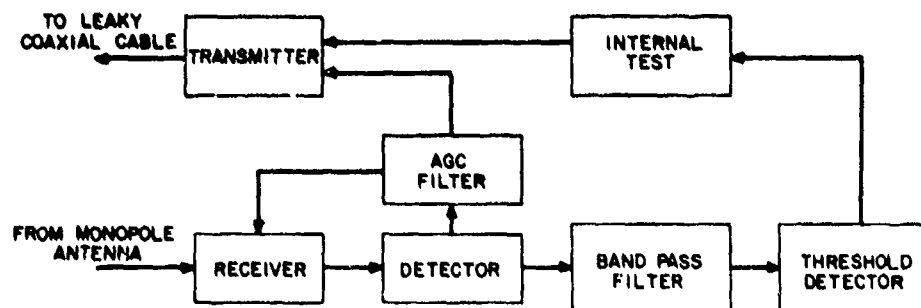


Figure 2. Simplified Block Diagram

The measurements were conducted on a single C-5A aircraft, parked on a concrete runway, with the plane both in the normal parking position and in the download position. In the normal parking position (see Figure 3) the lowest part of the fuselage is about 4 ft from the runway; in the download position, about 15 in. (see Figure 4). The tests investigated if the C-5A aircraft, because of its huge physical size (see Table 1, Reference 7) and its proximity to the runway in the download position would block any of the radiated signal from the leaky coaxial cable to the receiver monopole. If blockage occurred, it would mean that the system could not respond to an intrusion across the portion of the cable from which the blocked signal radiated.

7. Taylor, John W. R., Jane's all the world's aircraft 1976-77, Jane's Yearbook, London, England, pp 322-323.



Figure 3. Photo: C-5A in Up Position



Figure 4. Photo: C-5A in Download Position

Table 1. Dimensions of C-5A Aircraft

Dimensions	ft (approximate)
Length Overall	248
Wing Span	223
Height Overall	65
Tailplane Span	69
Wheel Track (between outer wheels)	37
Wheelbase (c/l main gear to c/l nose gear)	72

3. MEASUREMENTS

3.1 Discussion

For these tests, the variation in received power was recorded as a person walked around the aircraft, immediately adjacent to the cable, beginning at the tail. These tests were called "circumferential walks". Previous measurements had indicated that the amplitude of signal changes so produced was directly related to the detection sensitivity of the system to radial penetrations.⁴ Therefore, the system response to penetration at any angle could be calculated from the circumferential walk results.

The leaky coaxial cable (CERT 285, perimeter = 750 ft) which lay on the concrete runway encircled the C-5A; passed beneath the nose and tail and a few feet beyond the wing tips. Energy was fed into one end of the cable, while the other was terminated in a matched load. The feed and load ends were positioned within a few feet of each other to form a closed loop, and were located, as shown in Figure 1, at an azimuth of 340° (about 43 ft, along the cable arc, from the tail.)

The support electronics discussed in connection with Figure 2 are undergoing separate evaluation and will not be further discussed here. A block diagram of the experimental setup that was used during the tests is shown in Figure 5. A network analyzer was used for the transmitter-receiver, providing a broad range of frequencies and detection sensitivities. The receiver output signal was recorded on the y-axis of an x-y recorder. The x-axis was calibrated in terms of azimuth angle, radial distance, tangential distance, or time. Two attenuators and a pair of coaxial switches were used to calibrate the receiver-recorder and to compensate for the attenuation in the feed cable. The measurements were performed at 75 MHz since previous tests showed that the results at 75 MHz were representative of those at other frequencies in the range of 50 to 100 MHz. The input power to the cable was 10 mW, although the radiated power was considerably less than this because leaky

coaxial cable is a very inefficient radiator. The leaky coax to monopole coupling loss ranged from 60 dB to 110 dB, with 85 dB typical.

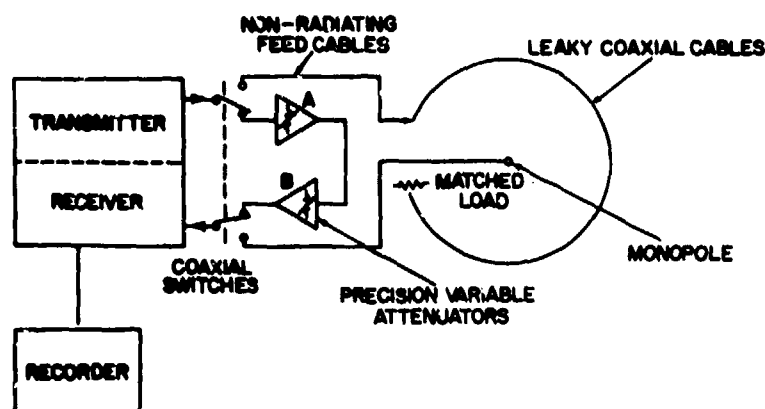


Figure 5. Block Diagram of Experimental Setup

When the C-5A is in the up or normal parking position, the bottom of the fuselage is about 4 ft above the ground. At 75 MHz, a quarter-wavelength monopole is 3-1/3 ft high and can fit beneath the fuselage. The first grouping of tests investigated system response using one and two monopoles as the receiving antennas, placed at various positions along the longitudinal center line of the aircraft beneath the aircraft. However, in the download position, a quarter wavelength monopole cannot fit beneath the fuselage which is only 15 in. from the ground. So two monopoles were used, connected in parallel, one on each side of the fuselage. These monopoles were placed in various positions relative to each other and to the aircraft. Figure 6 identifies the positions where the monopoles were placed.

3.2 Aircraft - Up Position

In the first series of tests, with the plane in the up position, a single quarter-wavelength monopole was placed at various locations beneath the fuselage, along the longitudinal center of the aircraft. In reading all the system response graphs, the 0 dB level is the quiescent signal level taken as the base amplitude level. Intruder caused signal amplitude changes varied about this base. This a 5 dB amplitude change (with a quiescent signal level of -80 dBm) means that the intruder caused the quiescent signal to change to either -75 dBm or -85 dBm.

The system response to a circumferential walk is shown in Figures 7, 8, 9, and 10 for the monopole placed 25 ft aft of the longitudinal center (D_0), at the center (A_0), and 25 ft (B_0) and 50 ft (C_0) forward of the longitudinal center.

The poorest overall system response occurred when the monopole was placed aft of the center, but improved as the antenna was moved forward of this position. The best response was obtained with the monopole placed in the forward positions at either B_0 or C_0 .

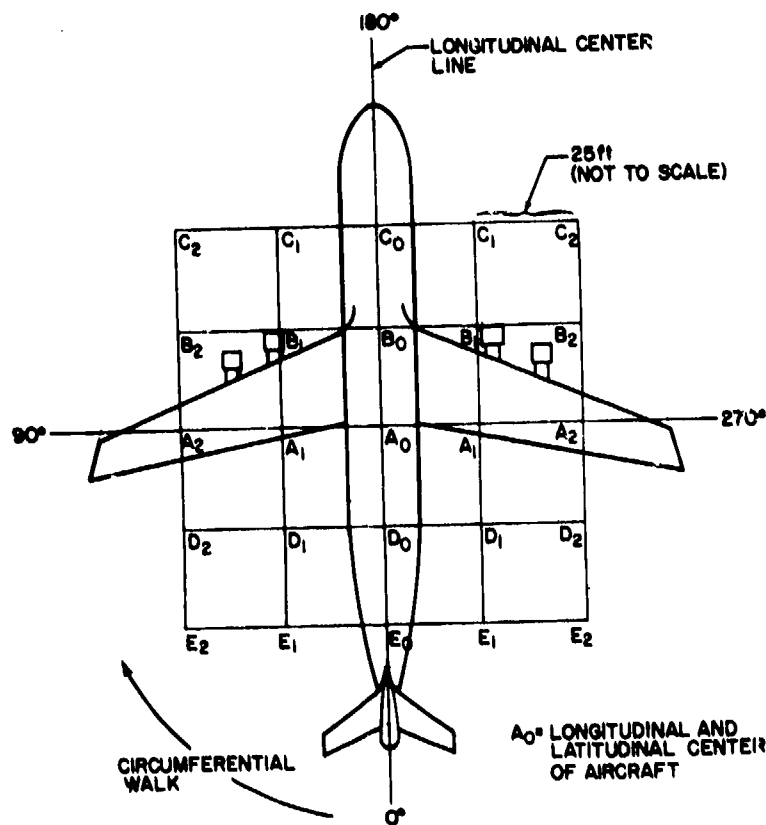


Figure 6. Diagram of Monopole(s) Position

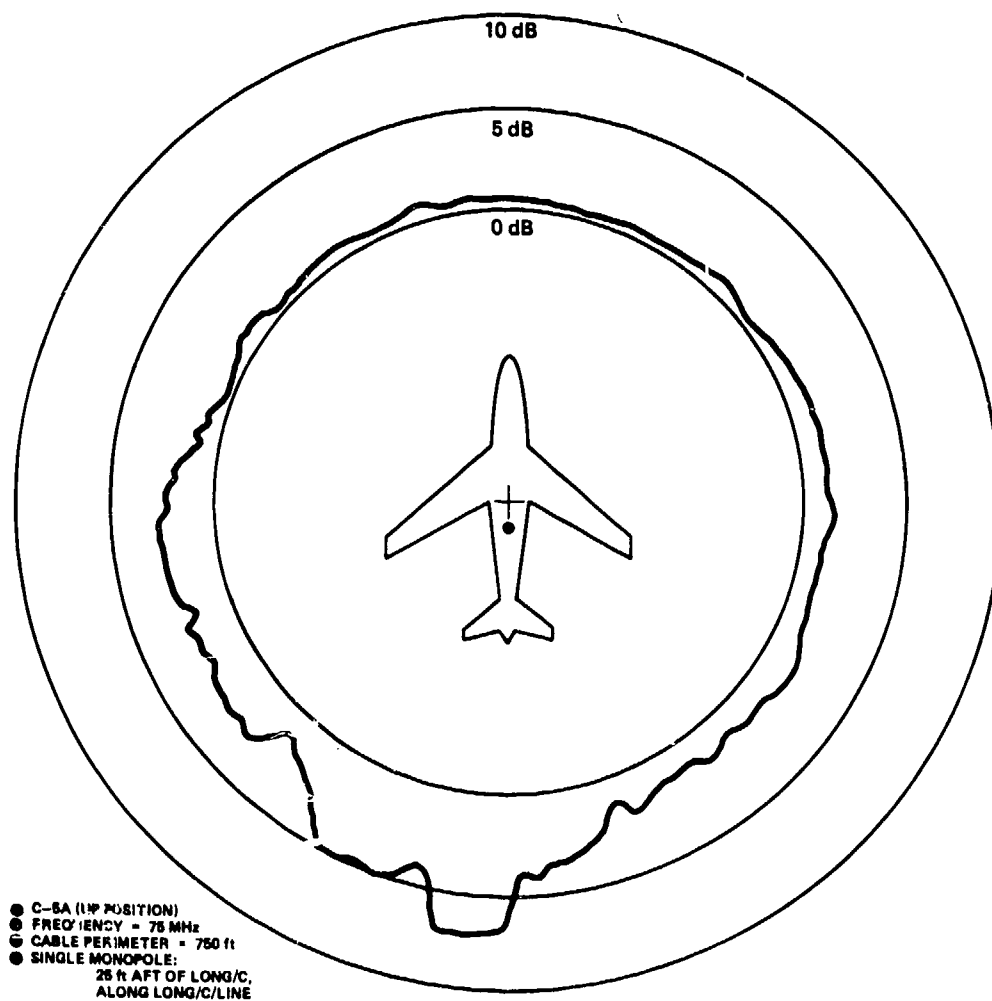


Figure 7. Plane Up—Single Monopole—25 ft Aft (D_0)

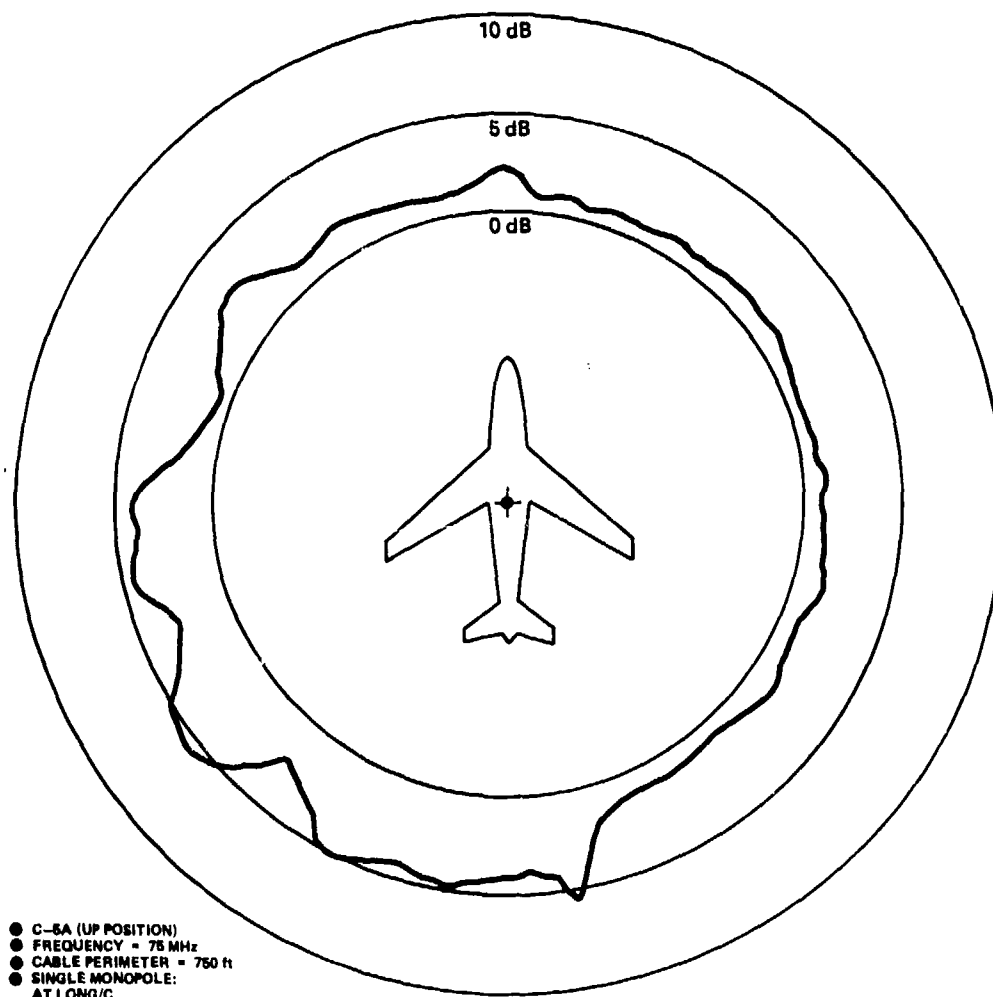


Figure 8. Plane Up—Single Monopole—Center (A_0)

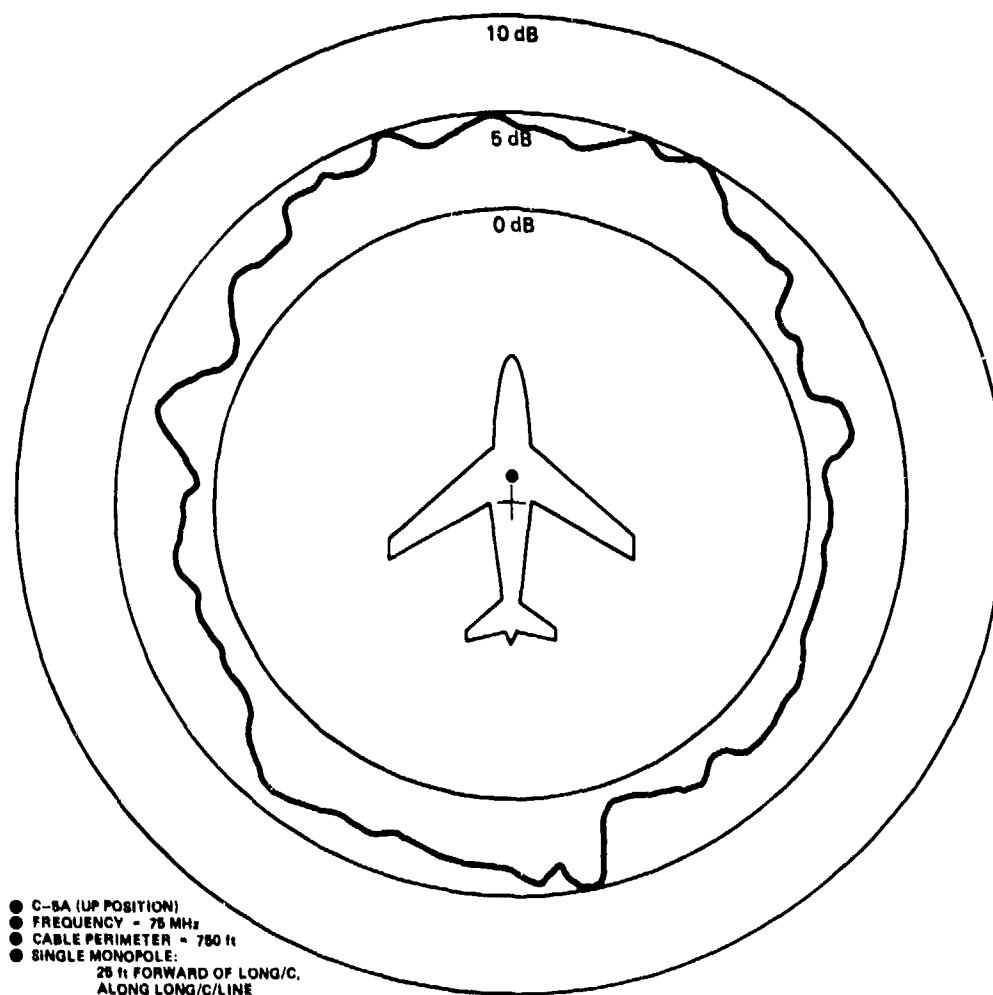


Figure 9. Plane Up—Single Monopole—25 ft Forward (B_0)

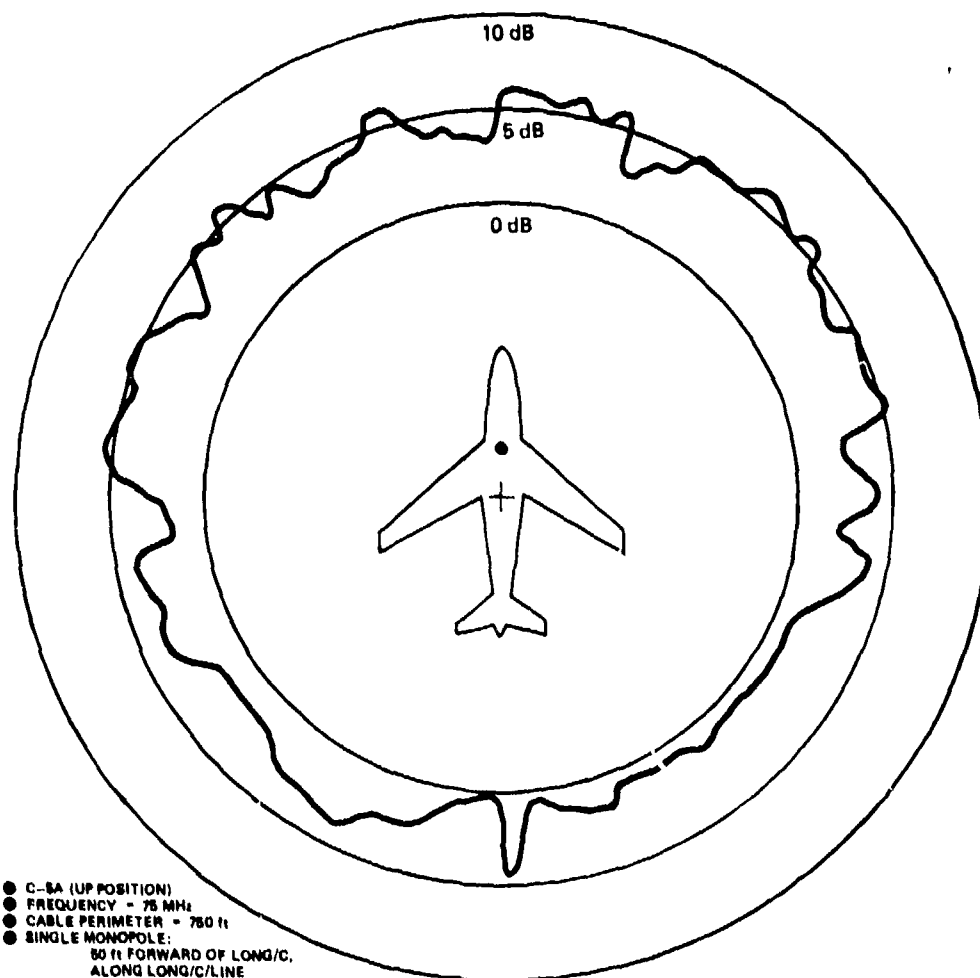


Figure 10. Plane Up-Single Monopole-50 ft Forward (C_0)

Note that there is no masking of the received signal at any azimuthal angle for either of these two forward positions. The response is strong in the first three quadrants. Only in the last quadrant, which contains the load end of the leaky cable, can the response be considered marginal. Even here, though, final system effectiveness (probability of detection will depend upon where the alarm threshold level is set. Figure 11 shows the superposition of the previous two figures for direct comparison. Of these two positions it appears that "50 ft forward" gives the best overall coverage. Figure 11 also points to another property of this system: actual antenna position relative to the aircraft is not critical. System response does not change significantly if the actual antenna position differs from the optimum position by a few feet.

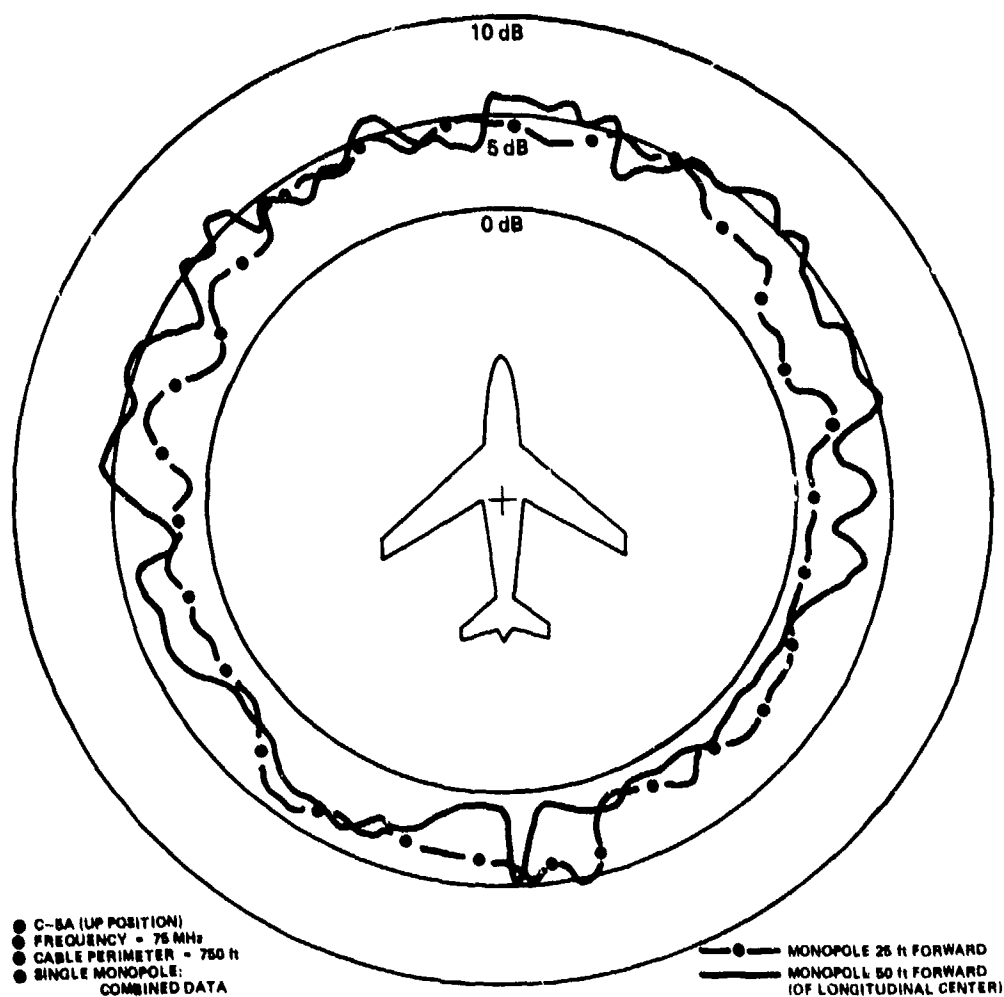


Figure 11. Plane Up—Single Monopole—Combined Data

The next series of tests (aircraft up) used two monopoles connected to the receiver through a coaxial power splitter. The two monopoles were placed along the longitudinal center line (positions $B_0 D_0$ and $C_0 D_0$ respectively). Figures 12 and 13 show the system response. The $C_0 D_0$ position gives the strongest response. This response is 2 dB or greater around the entire periphery. In fact, for the greater portion of the periphery, the response is near 5 dB. Figure 14 superimposes the two previous figures for direct comparison.

In the final series of tests with the plane up, one antenna was placed on each side of the fuselage.

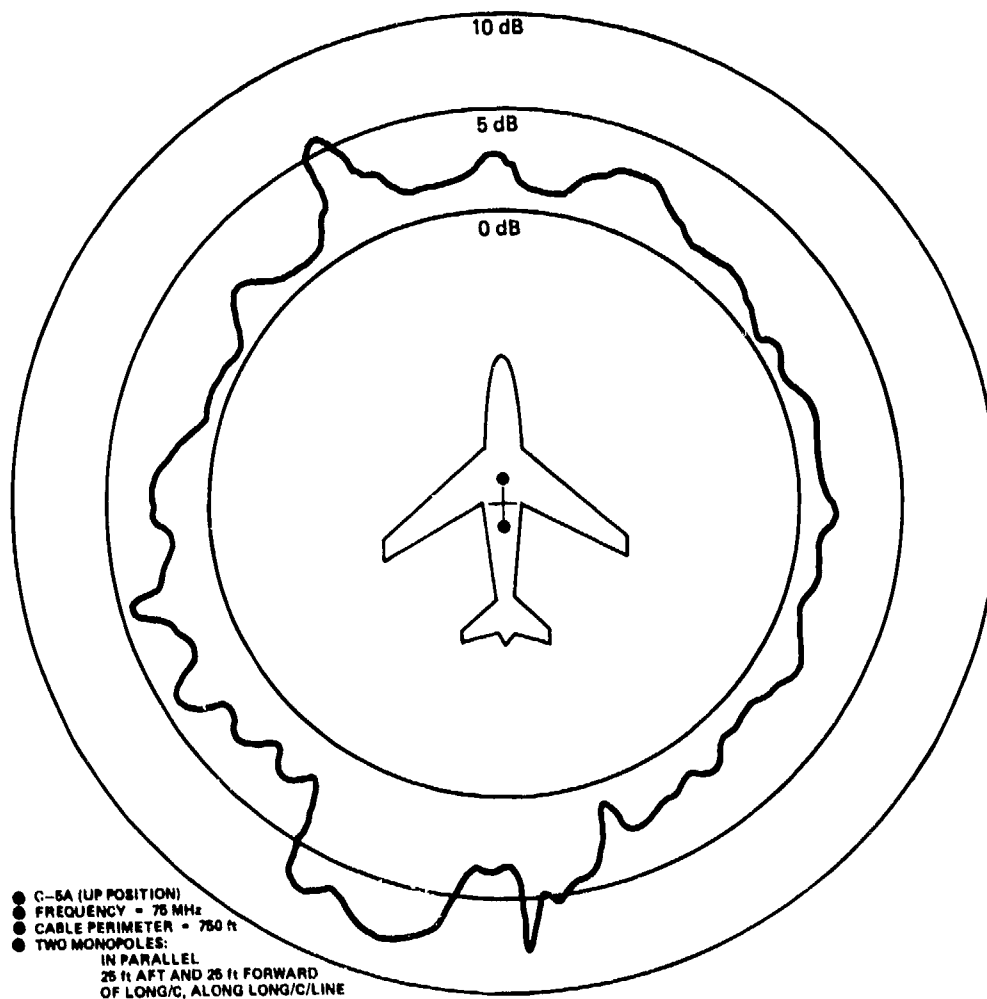


Figure 12. Plane Up—Two Monopoles—25 ft Aft/25 ft Forward ($B_0 D_0$)

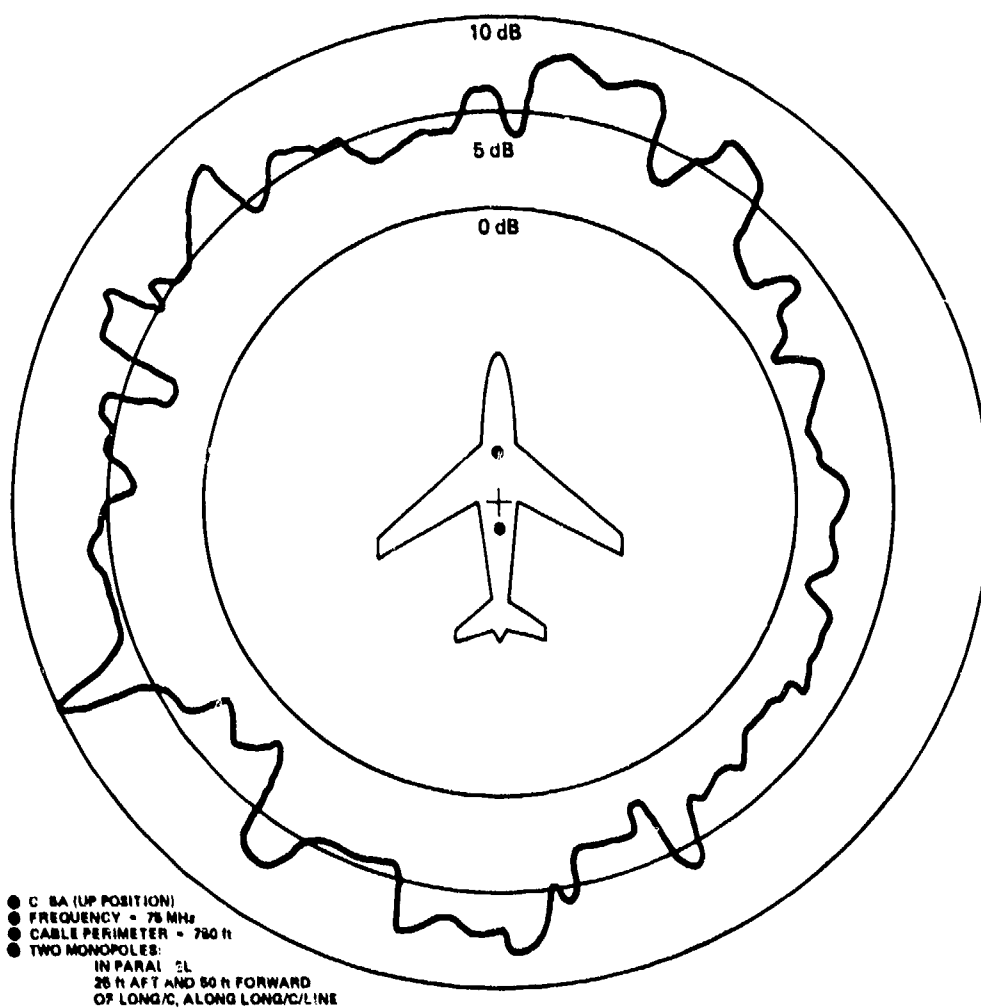


Figure 13. Plane Up—Two Monopoles—25 ft Aft/50 ft Forward ($C_0 D_0$)

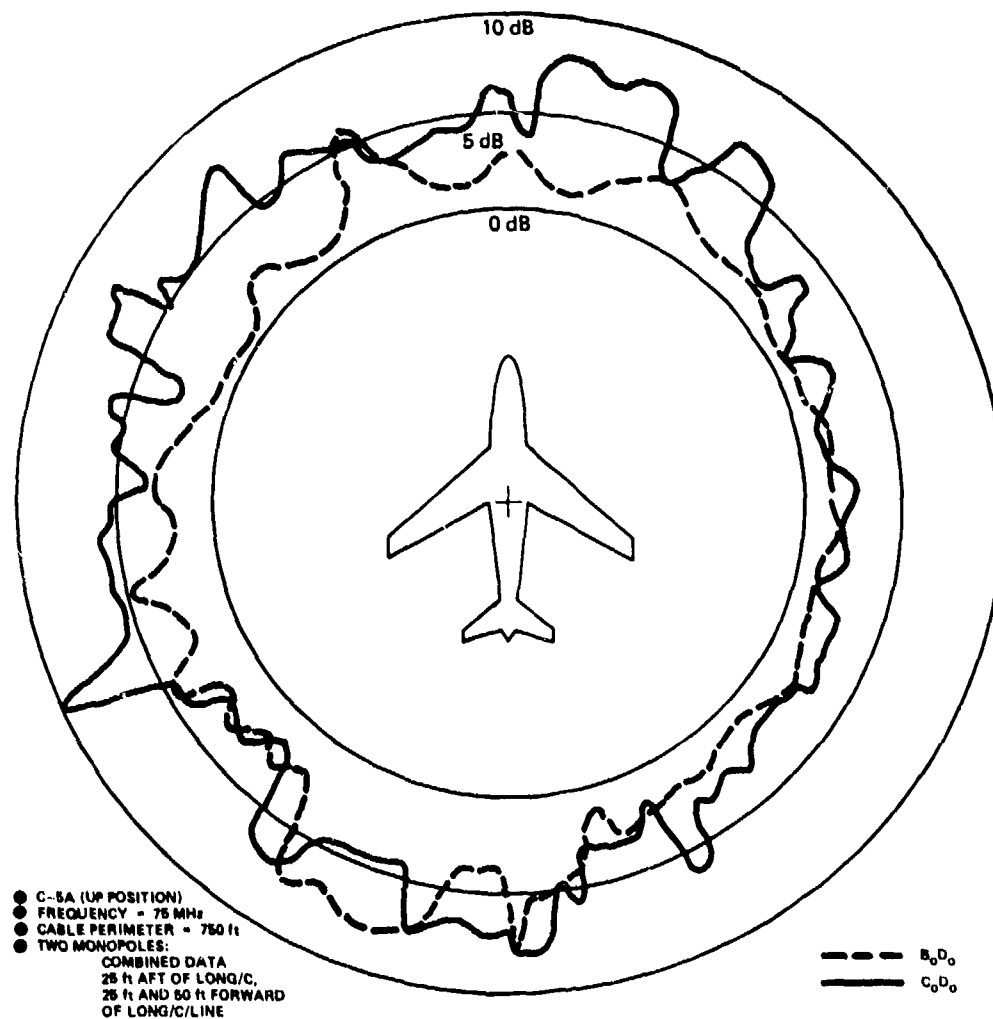


Figure 14. Plane Up—Two Monopoles—Combined Data

Figure 15 shows the two monopoles placed in a diagonal configuration at positions (C_1E_1). Except for the second quadrant (90° to 180°) the response is low, therefore this antenna placement is not suitable.

Next the two monopoles were placed at the same transverse line and then the two were moved together to various locations along the longitudinal axis. Figures 16, 17, and 18 show the system response with the 25 ft aft (D_1D_1), center (A_1A_1) and 25 ft forward (B_1B_1) respectively. Good overall system response is obtained with the antennas in the aft (D_1D_1) or center (A_1A_1) locations. All azimuthal angles are covered and the amplitude response, for the greater portion of the periphery, is greater than 1 dB.

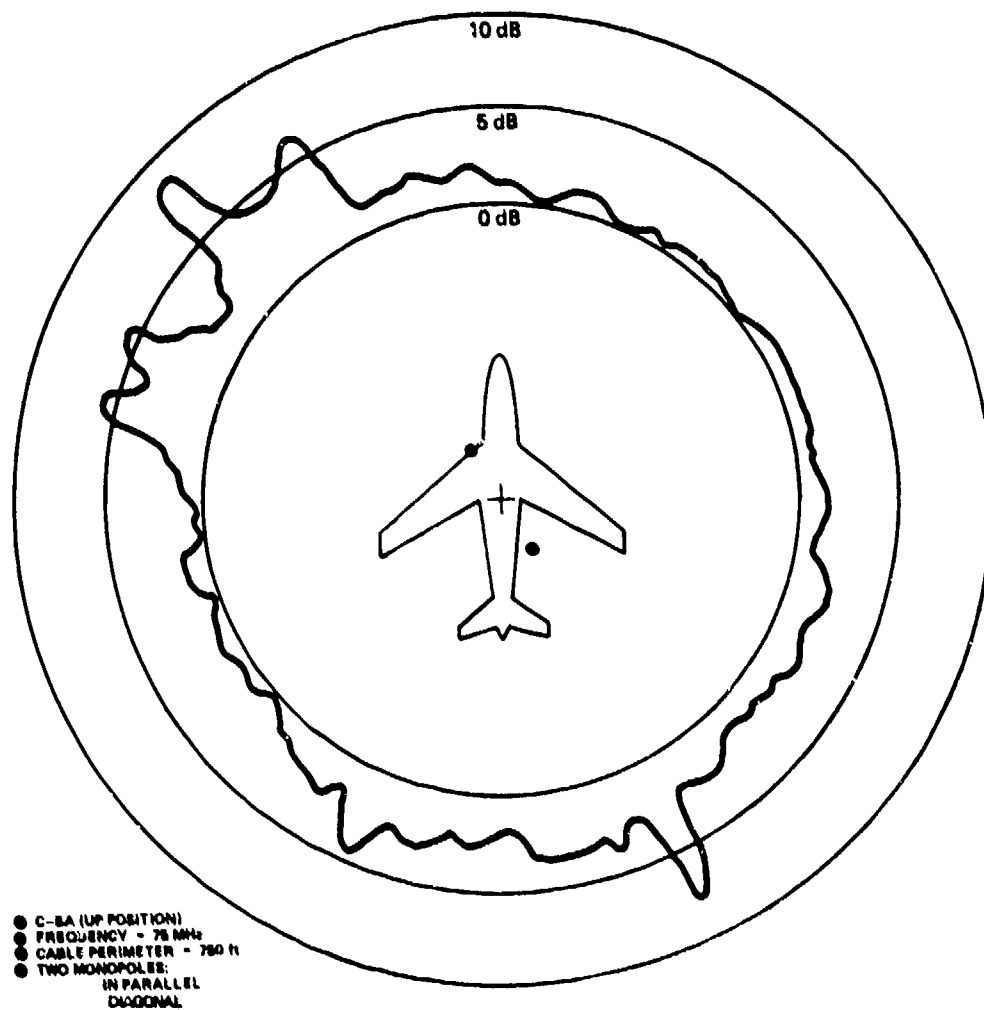


Figure 15. Plane Up—Two Monopoles—Diagonal (C_1E_1)

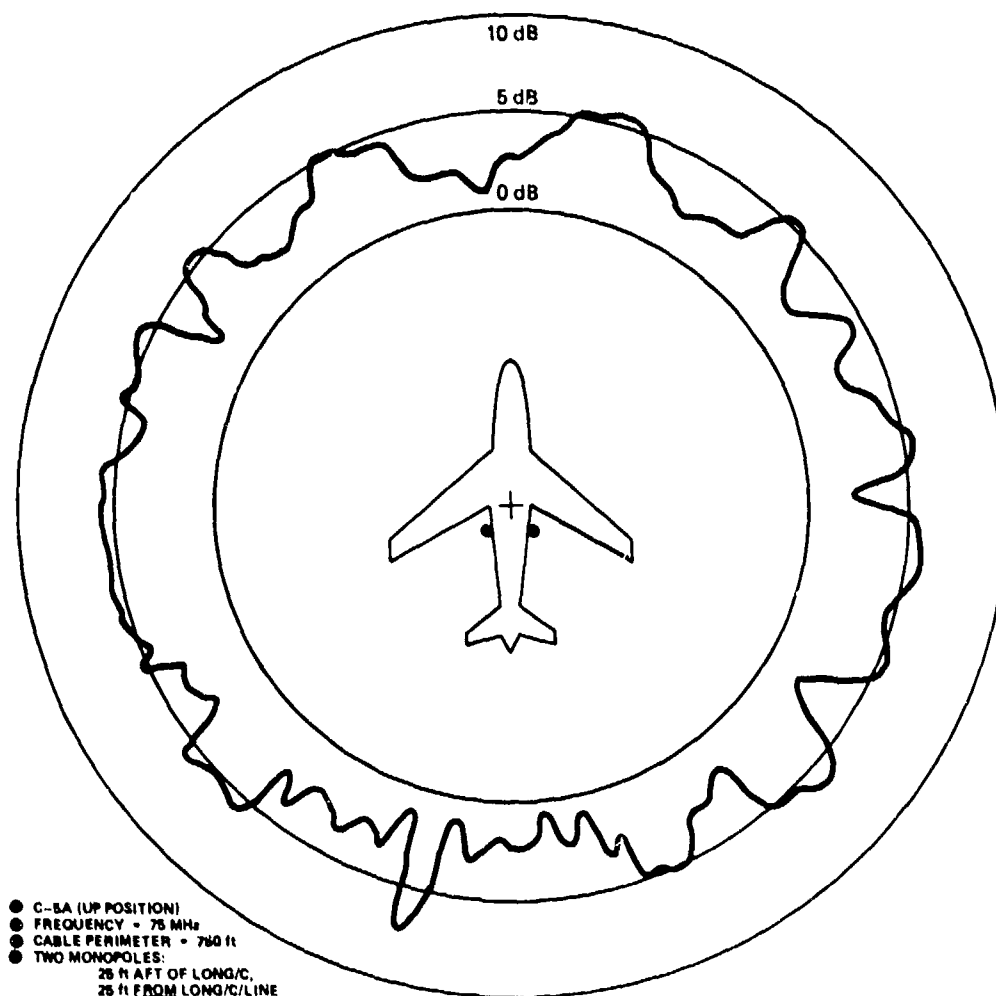


Figure 16. Plane Up—Two Monopoles—25 ft Aft ($D_1 D_1$)

Figure 17 also shows the threshold level that gives a probability of detection of 0.95 for that system configuration. This probability of detection gives the probability of sensing an intruder penetrating a randomly selected location if this change in received signal is required to declare a detection. Specifically, for this antenna configuration, an intruder will produce a signal change of 1 dB or greater 95 percent of the time.

Note that the amplitude response in the figure does not drop below the threshold level of 1 dB, which might seem to indicate a $P_D = 100$ percent. However, this is not so because the response curve represents an average of the raw data. An examination of the raw data would show that the system response was below 1 dB for 5 percent of the intrusions.

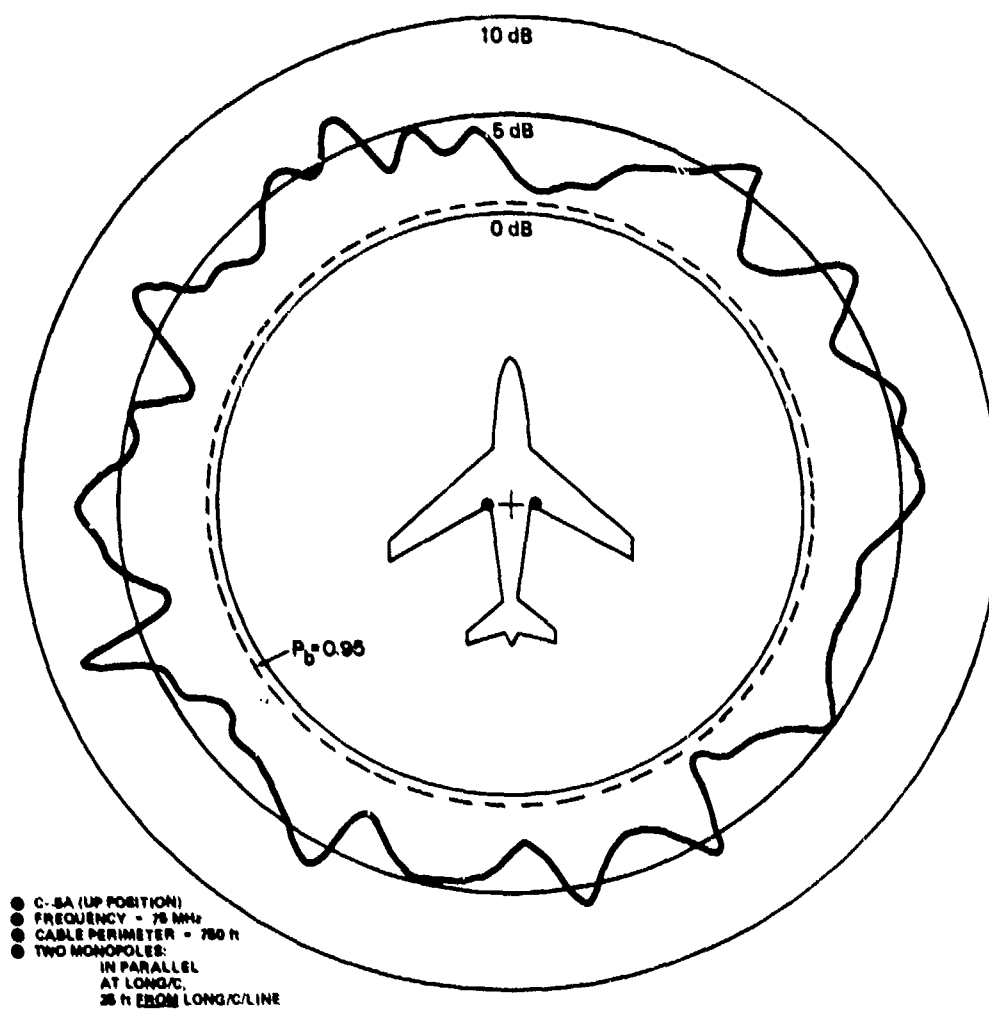


Figure 17. Plane Up—Two Monopoles—Center (A_1A_1)

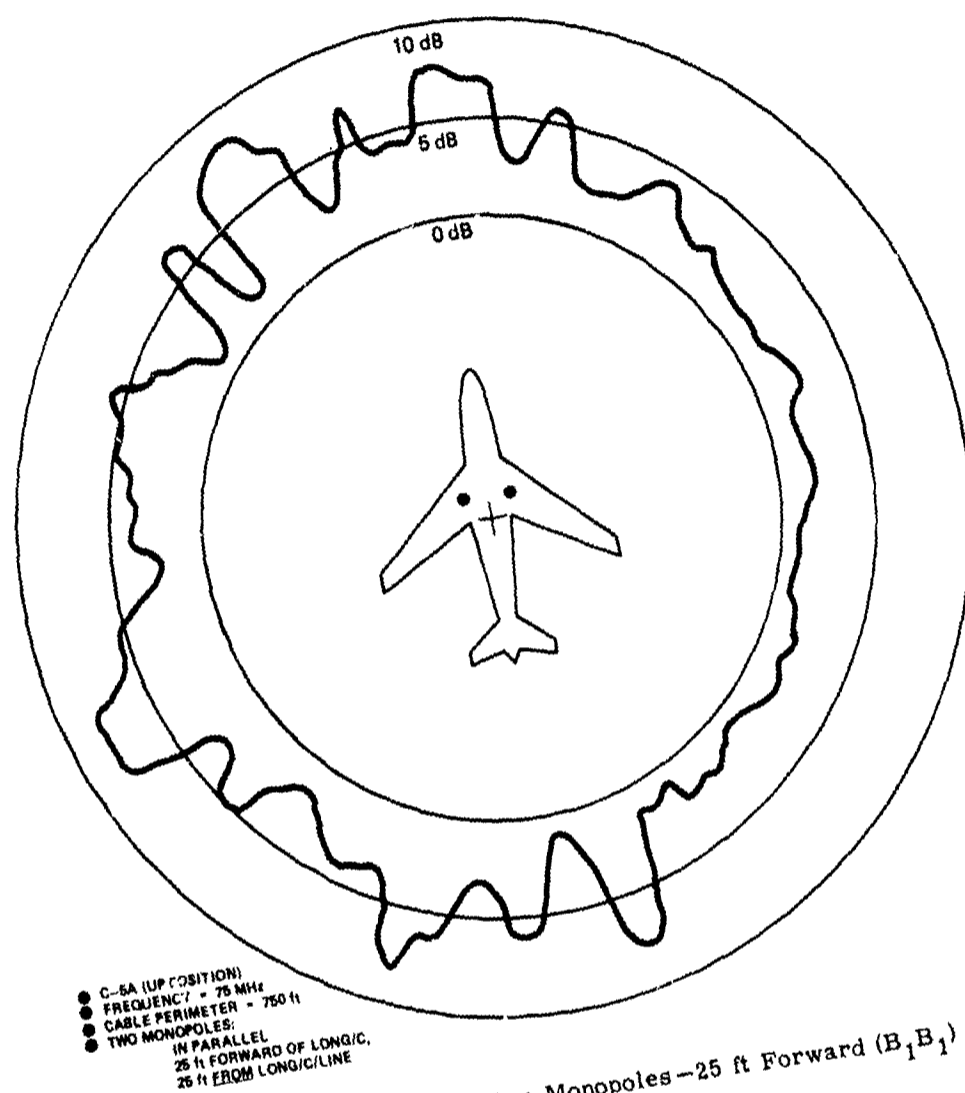


Figure 18. Plane Up—Two Monopoles—25 ft Forward (B_1B_1)

Finally, the two antennas (plane up) were placed 50 ft from the fuselage (along the same transverse line) and 25 ft forward of the longitudinal center (position B_2B_2). (See Figure 19.) The system response was particularly poor in the fourth quadrant. It appears that a distance of 25 ft from the fuselage is an optimum placement position for the receiving antennas.

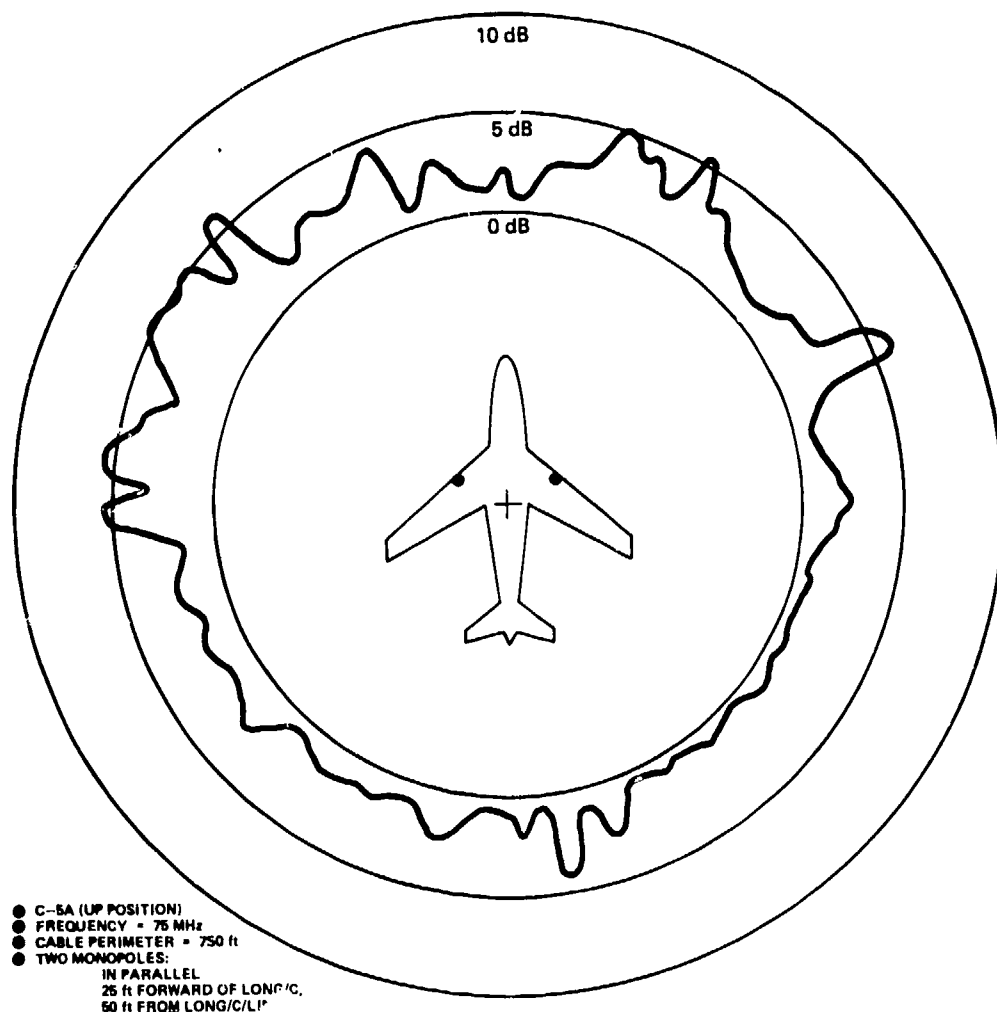


Figure 19. Plane Up—Two Monopoles--25 ft Forward (B_2B_2)

3.3 Aircraft — Download Position

When the C-5A aircraft is in the download position (see Figure 4) the lowest part of the fuselage is approximately 15 in. from the runway. The quarter-wave-length monopole used during the preceeding tests cannot fit beneath the aircraft. Therefore two antennas were used, connected in parallel through a coaxial in-phase power splitter, with one antenna placed on either side of the lowered fuselage.

Figures 20, 21, 22, and 23 show the system response for the two antennas each 25 ft from the fuselage along the same latitudinal line, placed at various positions from the longitudinal center: 25 ft aft (D_1D_1), center (A_1A_1), 25 ft forward (B_1B_1) and 50 ft forward (C_1C_1) respectively.

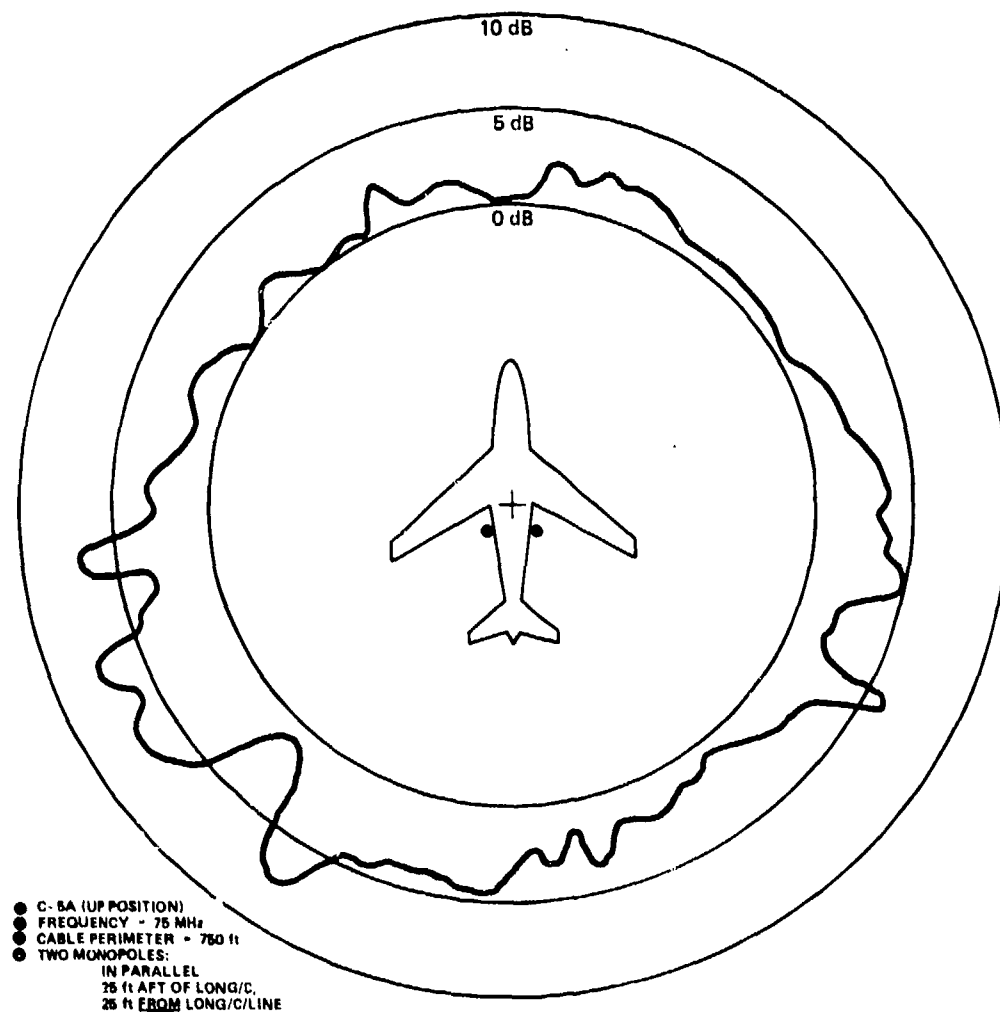


Figure 20. Plane Down—Two Monopoles--25 ft Aft ($D_1 D_1$)

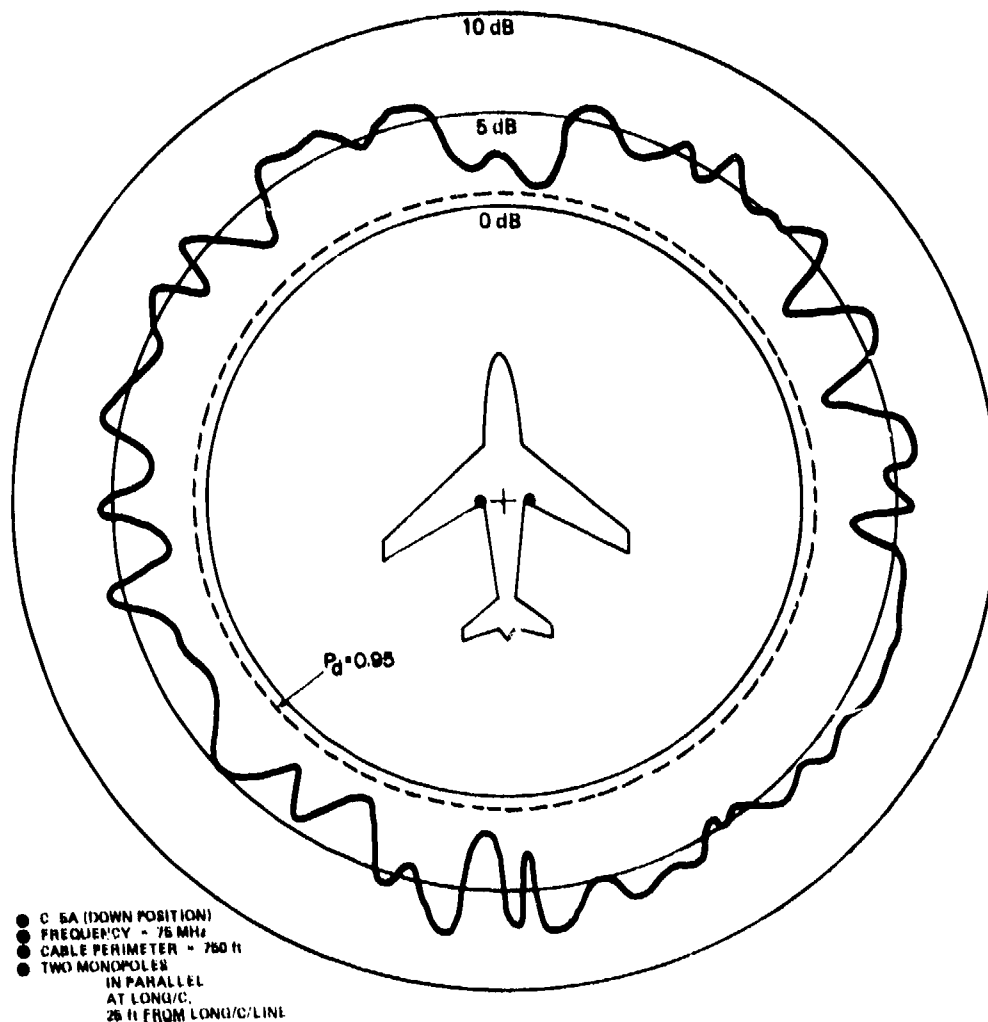


Figure 21. Plane Down—Two Monopoles—Center (A_1A_1)

Of the four antenna configurations, the center placement (A_1A_1) gives the best overall system response. All azimuthal angles are covered and the system response amplitude is strong. For most azimuthal angles, the amplitude response level is about 5 dB or higher. Also shown in Figure 21 is the threshold level for a probability of detection of 0.95.

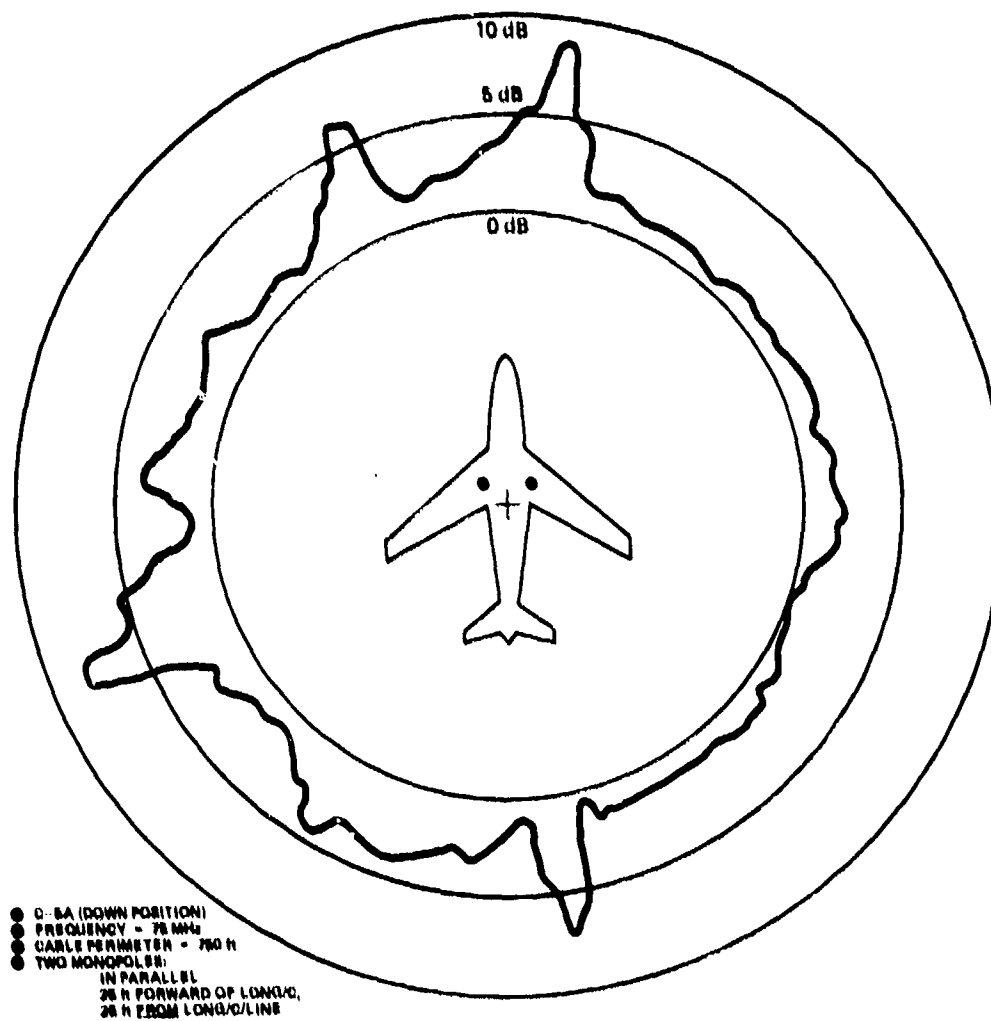


Figure 22. Plane Down—Two Monopoles—25 ft Forward (R_1, R_1)

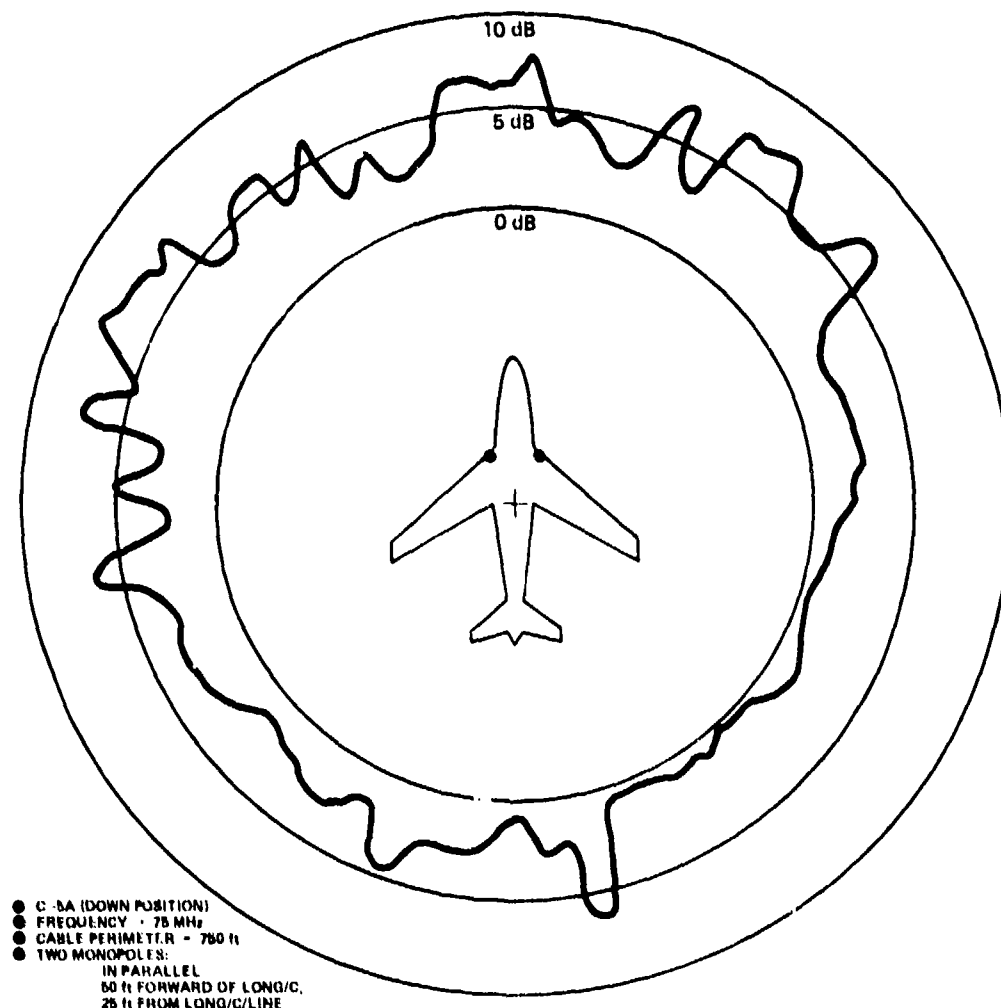


Figure 23. Plane Down—Two Monopoles—25 ft Forward (C_1C_1)

A direct comparison between the system responses (antennas at the center A_1A_1) with the plane up and with it down, is shown in Figure 24. Also shown is the threshold level for a probability of detection of 0.95. As can be seen, the intrusion system protects the aircraft whether it is up (in the normal parking position) or in the download position. This means that, once the antennas are placed at A_1A_1 , they do not have to be re-positioned if the aircraft is lowered or raised from its original position.

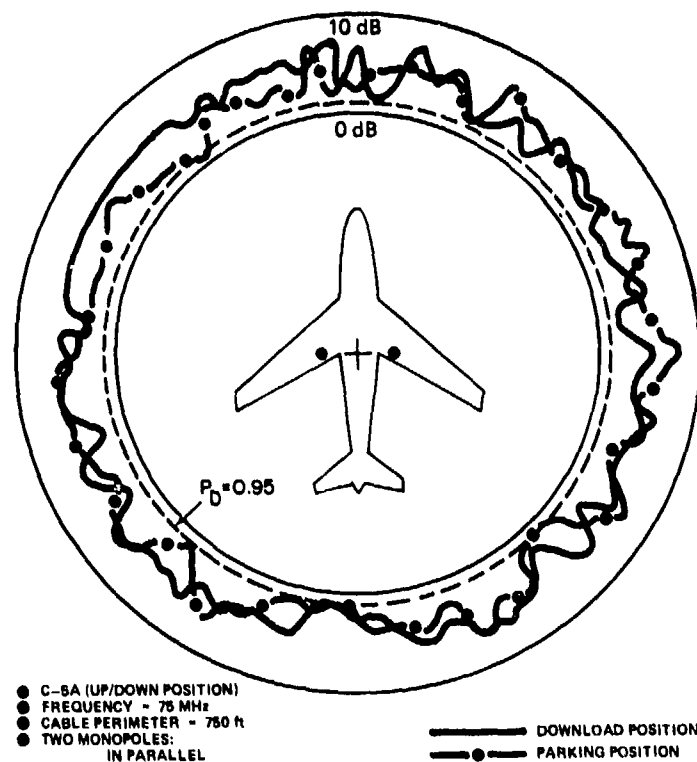


Figure 24. Plane Up/Down—Two Monopoles

As a last test configuration, two antennas were placed in a diagonal line (position C_1E_1) as shown schematically in Figure 25. The system response is low for some portions of this periphery in the first and third quadrants; although only at a few azimuthal angles does the response drop below 1 dB. Still, the diagonal configuration is less suitable for use than the two antennas placed on the same latitudinal line.

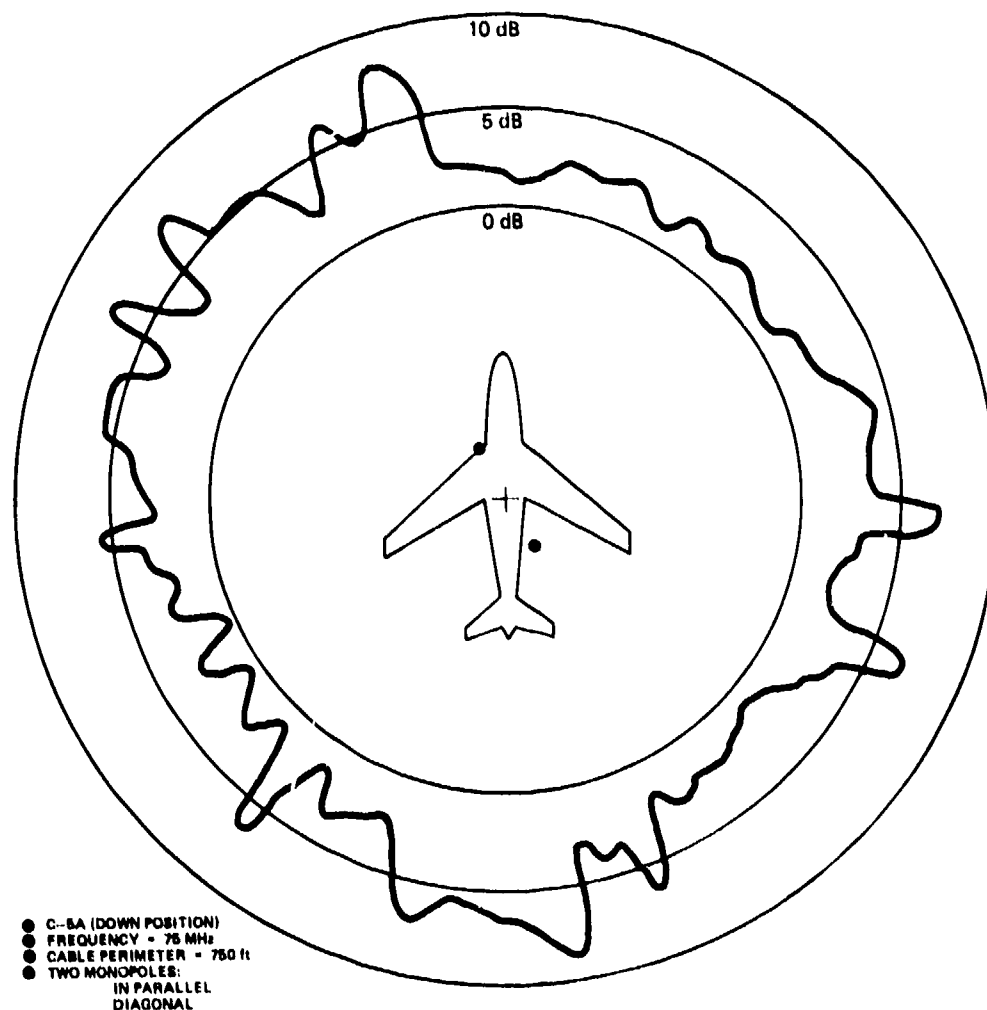


Figure 25. Plane Down—Two Monopoles—Diagonal (C_1E_1)

4. SUMMARY AND CONCLUSIONS

The results of the tests of this VHF Intruder Detection System shows the feasibility of using this system to protect any large parked aircraft.

Specifically the tests demonstrate that the system protects a C-5A aircraft whether in the parking or the download positions without changing the relative locations of the components of the system. By proper placement of two receiving monopole antennas complete coverage is obtained with no masking from the aircraft structure. With each of the monopoles placed 25 ft from the center line, system amplitude response for both up and down positions, remains above an alarm

threshold of 1 dB which corresponds to a probability of detection of 0.95, at all azimuthal angles. Further tests showed that, for this configuration, optimum antenna placement is about 25 ft from the longitudinal center line no matter where along the length of the fuselage the antennas are placed. Also, the tests showed that the system response does not change significantly if the antenna position differs from the optimum position by a few feet.

With the C-5A aircraft in the up or normal parking position, either a single antenna or two antennas were used. In both configurations antenna placement was directly beneath the fuselage. A single monopole 50 ft forward of the longitudinal center gave a system amplitude response equal to or greater than 1 dB (corresponding to a $P_d = 0.95$) at all azimuthal angles. Two antennas in parallel (one placed 25 ft aft, the other 50 ft forward of the longitudinal center, along the longitudinal center line) gave a system amplitude response equal to or greater than 2 dB at virtually all azimuthal angles.

In conclusion, the tests demonstrated the feasibility of using this VHF Intruder Detection System to protect the C-5A or similar large parked aircraft.

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